Evaluation of Boiler Maintenance Using the Failure Mode and Effect Analysis Approach at KM. Tilongkabila

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Abstract— A boiler is a closed vessel containing water/fluid to produce steam at a predetermined pressure. Boilers can be used to heat fuel, heat lubricating oil if necessary, and the steam produced by the boiler can also be used as an auxiliary medium for preheating the main engine to maintain a constant temperature. Boilers often experience frequent problems, such as scale formation, unstable steam pressure, incomplete combustion, and difficulty in starting operation. Therefore, this research uses a quantitative method with the Failure Mode and Effect Analysis (FMEA) approach, which aims to determine maintenance and prevention to minimize these problems. This method determines the failure priority obtained from the Risk Priority Number (RPN) calculation based on assessment factors such as severity, frequency of occurrence, and the likelihood of failure being detected in each component. This research obtained source data from observations, interviews, maintenance records, maintenance guidelines, and maintenance schedules at KM. Tilongkabila. The results of these calculations indicate that the steam drum component falls into the highest category with a total RPN value of 32. Therefore, the recommended improvements based on the FMEA results can be used as evaluation material to ensure the effectiveness of the improvements. Furthermore, regular boiler maintenance and monitoring are required, especially for components such as the steam drum, which requires additional routine maintenance schedules, repeated evaluations related to water treatment, and determining appropriate repairs for any steam drum failures.

Keywords— Boiler, FMEA, Quantitative

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I. INTRODUCTION

Indonesia is a maritime country, with most of its territory consisting of water, where the land area is smaller than the sea area. Indonesia has a total area of 1,892,410.09 km², with 77.14% of that area being water [1]. 90.88% of imports and 95.54% of exports in Indonesia use sea transportation as their primary mode of transport compared to other modes of transportation [2]. Efficient operation of ship operations as a means of maritime transportation must be supported by reliable machinery, both in terms of the main engine and auxiliary machinery. One example of auxiliary machinery is the steam boiler. Hot steam from the boiler can be used to heat fuel, lubricating oil, ship accommodations during cold weather, fresh water, and more [3].

A steam boiler is a closed vessel that can produce steam under pressure exceeding 1 atmosphere [4]. It is designed to produce high-pressure steam and large volumes with high thermal efficiency due to more effective heat transfer [5]. Boilers come in several types,

distinguished by factors such as characteristics, operating principles, fuel types, and pipe types [6]. The type of steam boiler at KM. Tilongkabila is a water tube boiler that can produce a steam flow of 4,500-12,000 kg/hour [7]. The working principle of a water tube boiler involves three main types of heat transfer: radiation, conduction, and convection [8]. The boiler uses the heat energy produced by burning fuel in the combustion chamber (furnace) to heat the water in the pipes until it turns into high-pressure steam [9]. Hot gases from combustion move through the gas pass, where most of their energy is absorbed by the evaporator tubes. This converts the water into saturated steam, where the liquid and vapor phases remain in equilibrium [10]. The process can then continue until superheated steam is produced, whose temperature exceeds the saturation temperature [11].

Several problems often occur in boilers, such as scalling, unstable steam pressure, incomplete combustion, and difficulty starting the engine. Therefore, evaluation of boiler maintenance is very necessary. Evaluation is the process of understanding how a subject works, whereby the data generated obtains information as a basis for determining decisions [12]. This research uses a failure mode and effect analysis approach. The Failure Mode and Effect Analysis (FMEA) method serves to analyze potential failures in a product, consider the level of risk associated with each type of failure, and develop corrective measures [13].

In this research, FMEA was used to analyze the main causes of damage to boilers and determine corrective and preventive strategies to prevent such problems from recurring, thereby improving boiler performance efficiency. This research aims to identify

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various factors causing and impacting each system failure in boilers, determine the risk level through Risk Priority Number (RPN) calculations in the FMEA method, and provide recommended improvement strategies to enhance boiler performance at KM.

Tilongkabila. This research was conducted while the researcher was conducting a sea practice on the KM. TILONGKABILA ship owned by PT. Pelayaran Nasional Indonesia (PELNI) Persero for 1 year and 5 days.

Figure. 1. KM. Tilongkabila

TABLE 1.
SHIP PARTICULAR KM. TILONGKABILA. (SOURCE : SHIP KM. TILONGKABILA)

Main Vessel Data	
Flag	: INDONESIA
Classification	: BKI
Imo Number	: 9102760
Type of Vessel	: PASSANGER
Ship Owner	: DIRJENHUBLA
Call Sign	: YFCD
Port of Registration	: 525 105 002
Shipyard	: JOSH L MAYER PAPENBURG GERMANY
Yearbuilt	: 1995
Classified	: BKI+A 1001
Class Code	: PASSANGER SHIP+SMO
Registration Mark	: GT.6022 No.294 / PRJ
Length Over All (LOA)	: 99.80 meters
Length Between Perpendiculars (LBP)	: 90.50 meters
Ship Width	: 18.00 meters
Dead Weight Tonnage (DWT)	: 1.438 tons
Gross Tonnage	: 6.022 tons
Net Tonnage	: 1.806 tons

TABLE 2.
TECHNICAL DATA SHEET BOILER AT KM. TILONGKABILA. (SOURCE : MANUAL BOOK FOR BOILER

Water Tube Boiler	
Maker	: AALBORG
Boiler Type	: AQ 12
Made by	: HCh/TV/220
Oil Burner Type	: L 5 Z
Steam Production	: 700 kg/h
Working Pressure	: 7,0 kg/cm²
Design Pressure	: 9,0 kg/cm²
Safety Valve Opens at	: 8,5 kg/cm²
Feed Water Temperature	: 50 °C
Air Temperature	: 40 °
Thermal Boiler Efficiency	: 83%
Gas Exit Temperature	: Appr. 380 °C
Flue Gas Flow	: Appr. 800 kg/h

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Figure. 2. Water Tube Boiler

II. METHOD

This research uses quantitative research methods, also known as traditional methods, because these methods have been used for a long time and have become traditional research methods. These methods are also called discovery methods, because they can be used to discover and develop new science and technology. The data used in this study are primary and secondary data. Primary data come from original or primary sources and not available in compiled form in the form of files [14]. Secondary data is a source of data that does not directly provide data to the data collector, for example through other people or through documents, and refers to information collected from existing sources.

1. Data Collection Technique

The data collection techniques used in this research are as follows:

a) Observation

Observation where researchers are directly involved in observing the object being studied or used as a source of research data, and also aims to identify problems that often occur in the boiler and the maintenance system used.

b) Questionnaire

A questionnaire used to collect data to determine the severity. occurrence, and detection value of each potential boiler failure that contains questions based on a predetermined scale. Components of the boiler used as statements in the questionnaire include:

1) Feed Water Pump
2) Steam Drum
3) Electroda
4) Photocell / Flame Eye Detector
5) Nozzle
6) Blower Fan
7) Selenoid Valve
8) Fuel Pump
9) Fuel Filter
10) Safety Valve
11) Blow Down Valve
12) Main Steam Valve
13) Scum Valve
14) Non Return Valve
15) Sight Glasses
16) Manometer

c) Interviews

Interviews with the ship's engine crew were conducted to collect data related to the causes of damage, the impacts caused, and maintenance measures that were not obtained from the questionnaire and observation results.

d) Documentation

Documentation in the form of instruction manuals and specifications listed in the boiler manual, as well as historical records of maintenance that had been carried out.

2. Data Analysis Technique

After collecting the necessary data, the next stage involves analyzing the data to transform it into accurate information. Data analysis techniques in quantitative research use descriptive statistics. Descriptive statistics are the presentation of data in the form of tables, graphs, pie charts, percentage calculations, and other [15]. The calculations in this study use the FMEA process, which is to determine the severity level, occurrence level, and detection level obtained from the questionnaire results. The questionnaire results will be checked for validity and reliability tests to ensure that they are valid and reliable. These results can then be used to calculate the risk priority number and will be categorized based on low, medium, and high levels [16]. FMEA is a method for analyzing the potential impact of a failure [17]. It can also reduce the risk of danger, especially risks with the highest risk priority [18].

III. RESULT AND DISCUSSION

This section presents the results of instrument testing from validity tests, reliability tests, and FMEA analysis applied to the boiler system on KM. Tilongkabila, with a focus on identifying critical components based on the level of damage and determining the main priorities for repairs [19].

1. Data Characteristics and Instruments

There were 35 respondents in this research, with positions that could be classified as key positions on board, such as Chief Engineer, 2nd Engineer, 3rd Engineer, 4th Engineer, and Electrician. Based on the data, the most numerous respondents were 4th Engineers.
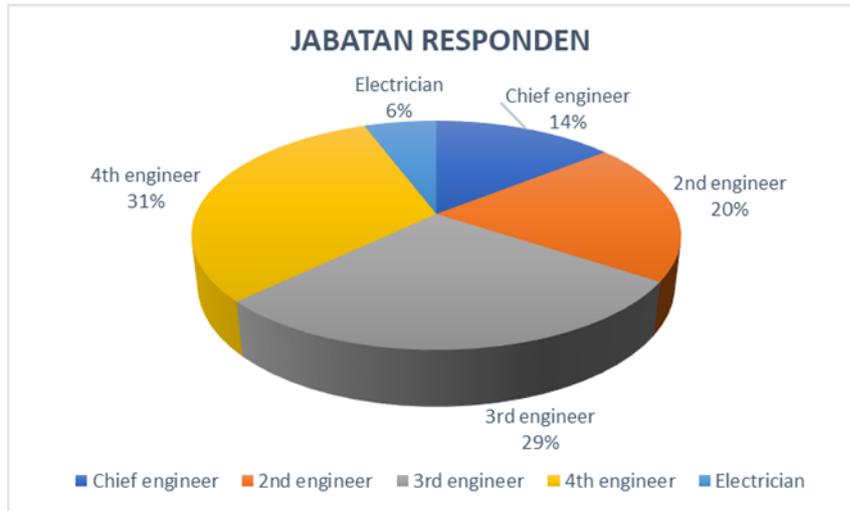

Figure. 3. Respondent Data

2. Results of Validity and Reliability Test

The results of the validity test using the product moment pearson correlation validity test, which aims to calculate the correlation between the scores of each question and the overall score of the respondents answers in the questionnaire, show that the three research variables in each item of the questionnaire meet the requirements if the value of $r_{calculated} > r_{table}$ and the value Sig. (2-tailed) < 0.05, then the data is considered valid so that it can be trusted and used in further tests.

TABLE 3.
VALIDITY TEST RESULTS (SOURCE: PROCESSED DATA)

Severity

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_10	S_11	S_12	S_13	S_14	S_15	S_16	Skor_Total	Standar
Pearson Correlation	.814***	.789***	.543***	.615***	.795***	.852***	.796***	.714***	.480**	.872***	.758***	.873***	.797***	.739***	.758***	.639***	1	0,334
Sig. (2-tailed)	0,000	0,000	0,001	0,000	0,000	0,000	0,000	0,000	0,003	0,000	0,000	0,000	0,000	0,000	0,000	0,000		0,05
N	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	
Hasil Uji	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	

***. Correlation at 0.001(2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Occurrence

	O_1	O_2	O_3	O_4	O_5	O_6	O_7	O_8	O_9	O_10	O_11	O_12	O_13	O_14	O_15	O_16	Skor_Total	Standar
Pearson Correlation	.576***	.519**	.725***	.583***	.570***	.607***	.662***	.787***	.506**	.425*	.560***	.567***	.662***	.744***	.546***	.734***	1	0,334
Sig. (2-tailed)	0,000	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,002	0,011	0,000	0,000	0,000	0,000	0,001	0,000		0,05
N	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	
Hasil Uji	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	

**. Correlation is significant at the 0.01 level (2-tailed).
***. Correlation at 0.001(2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed).

Detection

	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_10	D_11	D_12	D_13	D_14	D_15	D_16	Skor_Total	Standar
Pearson Correlation	.515**	.710***	.633***	.591***	.500**	.798***	.741***	.436**	.382*	.519**	.734***	.823***	.647***	.817***	.563***	.419*	1	0,334
Sig. (2-tailed)	0,002	0,000	0,000	0,000	0,002	0,000	0,000	0,009	0,024	0,001	0,000	0,000	0,000	0,000	0,000	0,012		0,05
N	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	
Hasil Uji	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	Valid	

*. Correlation is significant at the 0.05 level (2-tailed).
***. Correlation at 0.001(2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed).

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TABLE 4.
RELIABILITY TEST RESULTS (SOURCE: PROCESSED DATA)

Severity

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_10	S_11	S_12	S_13	S_14	S_15	S_16
Scale Mean if Item Deleted	47,34	47,26	48,17	48,11	47,29	47,20	47,83	47,69	48,57	46,66	47,94	47,23	47,43	47,57	48,00	48,14
Scale Variance if Item Deleted	106,408	106,667	116,382	114,928	112,328	107,988	111,323	111,398	117,487	100,879	112,173	107,476	108,664	111,252	114,118	113,538
Corrected Item-Total Correlation	0,776	0,746	0,496	0,566	0,767	0,825	0,766	0,669	0,421	0,837	0,723	0,849	0,760	0,698	0,729	0,588
Cronbach's Alpha if Item Deleted	0,939	0,940	0,945	0,944	0,940	0,938	0,940	0,942	0,946	0,938	0,941	0,938	0,940	0,941	0,941	0,943
Standar	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60
Uji Realibilitas	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel

Occurrence

	O_1	O_2	O_3	O_4	O_5	O_6	O_7	O_8	O_9	O_10	O_11	O_12	O_13	O_14	O_15	O_16
Scale Mean if Item Deleted	33,51	33,86	33,40	33,34	33,31	33,51	33,91	34,09	33,86	34,51	33,94	34,14	34,23	33,94	33,46	33,40
Scale Variance if Item Deleted	42,787	43,832	41,600	43,408	42,575	42,198	43,022	42,316	42,185	44,434	43,467	44,538	43,829	42,938	43,373	40,247
Corrected Item-Total Correlation	0,494	0,439	0,669	0,513	0,482	0,524	0,606	0,751	0,382	0,326	0,484	0,512	0,615	0,704	0,464	0,667
Cronbach's Alpha if Item Deleted	0,872	0,874	0,864	0,871	0,873	0,870	0,868	0,863	0,881	0,879	0,872	0,872	0,869	0,865	0,873	0,863
Standar	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60
Uji Realibilitas	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel

Detection

	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_10	D_11	D_12	D_13	D_14	D_15	D_16
Scale Mean if Item Deleted	30,94	29,63	30,91	31,11	30,77	30,89	30,60	31,03	31,06	30,71	30,80	30,29	30,66	30,20	31,03	31,37
Scale Variance if Item Deleted	44,173	38,711	42,963	44,045	43,946	42,751	41,600	45,382	45,055	43,092	41,224	39,798	41,232	39,224	43,793	44,534
Corrected Item-Total Correlation	0,447	0,619	0,573	0,538	0,423	0,769	0,692	0,376	0,297	0,429	0,680	0,781	0,568	0,769	0,499	0,331
Cronbach's Alpha if Item Deleted	0,885	0,881	0,881	0,883	0,886	0,876	0,876	0,887	0,890	0,887	0,876	0,871	0,881	0,871	0,883	0,890
Standar	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60
Uji Realibilitas	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel	Realibel

The reliability test results using Cronbach's Alpha reliability test can be used to assess whether a research instrument is reliable in the data collection process. The results indicate that the three research variables in each item of the questionnaire meet the requirements, whereby if the Cronbach's Alpha value for each item is > 0.60, the data is considered reliable or consistent and can be used as test data.

3. *Identification of Components and Failure Modes in Boilers*

Based on analysis of observation and interview results, there are several common failures that, if not addressed immediately, can reduce boiler efficiency [20]. The boiler components and failures referred to include scale buildup on the upper drum, lower drum, and pipes connected inside the steam drum, which causes water carryover and reduces steam capacity [21]; in components located inside the burner, such as electrodes that are too far apart or too close together, combustion failure will occur [22]; Photocell/flame eye detectors and nozzles usually fail due to accumulated dirt or abrasion; Meanwhile, failures in components such as blower fans, solenoid valves, fuel pumps, and fuel filters are caused by leaking seals, wear on bearings and rotors and damaged filters [23]; Boiler components also have various types of valves, such as blow down valves, main steam valves, and scum valves, which are commonly damaged by corrosion or clogging by scale or sludge, resulting in the valves not functioning properly and causing damage to the boiler system; Safety valve components can also experience corrosion, which can prevent the valve from opening automatically when wet steam reaches the maximum pressure limit of 21.5 kg/cm² or dry steam reaches a maximum pressure of 20.5 kg/cm² [24]; Meanwhile, non-return valves are also often affected by scale buildup, preventing them from preventing backflow to the feed water pump [25]; Next, damage to the feed water pump components caused by seal leaks, impeller wear, and cavitation, which affect the stability of the feed water flow, thereby reducing the amount of water supplied to the steam drum. Boilers also have measuring devices, such as sight glasses and manometers. Failure of measuring devices can also affect boiler efficiency due to seal leaks or malfunctioning measuring devices, resulting in inaccurate water level and pressure indications and causing thermal damage, overpressure, or under pressure.

TABLE 5.
CAUSES AND EFFECTS OF FAILURE (SOURCE: PROCESSED DATA)

No.	Component	Failure Cause	Failure Mode	Failure Effect
1.	Feed Water Pump	Seal leakage, abrasion on impeller, cavitation	Unstable feed water flow	Reduced water supply to the steam drum.
2.	Steam Drum	Scale, Corrosion	Reduced steam capacity	Disrupted steam transfer, water carryover
3.	Electroda	Rust buildup, abrasion on electrode tips	Failure to ignite, unstable spark	Engine difficult to start, incomplete combustion
4.	Photocell / Flame Eye Detector	Dirty/covered in soot, sensor damaged	Unable to detect flame	Boiler trip/unsafe condition (fuel leak)
5.	Nozzle	Clogged with dirt, Abrasion on the nozzle	Uneven fuel atomization	Incomplete combustion, temperature fluctuations
6.	Blower Fan	Abrasion on bearings, dirt	Reduced air flow	Incomplete combustion, overheating

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CONTINUED TABLE 5.
CAUSES AND EFFECTS OF FAILURE (SOURCE: PROCESSED DATA)

No.	Component	Failure Cause	Failure Mode	Failure Effect
7.	Selenoid Valve	Coil burned out, seal leaking	Valve opening/closing not as commanded	Flow disturbance in the system / trip
8.	Fuel Pump	Leaky seal, abrasion on rotor	Decreased fuel pressure	Incomplete combustion, difficult to start
9.	Fuel Filter	Filters damaged, clogged with dirt	Limited fuel flow	Damage to nozzles and fuel pump, incomplete combustion
10.	Safety Valve	Corrosion	Does not work during overpressure	Boiler damage / emergency shutdown
11.	Blow Down Valve	Corrosion, scale buildup	Unable to remove scale/sludge	Decreased thermal efficiency, fouling
12.	Main Steam Valve	Corrosion	Corrosion Steam leakage	leakage Steam pressure fluctuations
13.	Scum Valve	Clogged with mud	Ineffective drainage	There is dirt on the steam line
14.	Non Return Valve	Abrasion on seals, corrosion, reverse installation	Backflow	Feed water pump damage, pressure fluctuations
15.	Sight Glasses	Damaged, seal leak	Inaccurate drum level	Protection trip, thermal damage
16.	Manometer	Leaks, bourdon tube damage	Inaccurate pressure readings	Overpressure / underpressure

4.   Severity, Occurrence, and Detection Analysis

Based on the results of the Severity, Occurrence, and Detection assessments, there are variations in the level of risk for each failure mode. The severity value is relatively moderate, but the safety valve has the highest severity value, which means it has a very high level of severity in the event of damage. The impact of such damage could result in serious failure, causing significant losses and threatening safety. Meanwhile, the occurrence value is relatively moderate, but the safety valve component has the lowest occurrence value, which means that if the safety valve fails, such a failure has almost never occurred before and has a very small possibility compared to other components. Finally, the detection value shows various levels of component detection capability, ranging from very easy to detect to very difficult to detect.

TABLE 6.
SEVERITY, OCCURRENCE, DETECTION ANALYSIS (SOURCE: PROCESSED DATA)

NO.	COMPONENT	SEVERITY SCORE (S)	OCCURRENCE SCRORE (O)	DETECTION SCORE (D)
1.	FEED WATER PUMP	4	3	2
2.	STEAM DRUM	4	2	4
3.	ELECTRODA	3	3	2
4.	PHOTOCELL/ FLAME EYE DETECTOR	3	3	2
5.	NOZZLE	4	3	2
6.	BLOWER FAN	4	3	2
7.	SELENOID VALVE	3	2	2
8.	FUEL PUMP	3	2	2
9.	FUEL FILTER	2	2	2
10.	SAFETY VALVE	5	1	2
11.	BLOW DOWN VALVE	3	2	2
12.	MAIN STEAM VALVE	4	2	3
13.	SCUM VALVE	4	2	2
14.	NON RETURN VALVE	3	2	3
15.	SIGHT GLASSES	3	3	2
16.	MANOMETER	3	3	1

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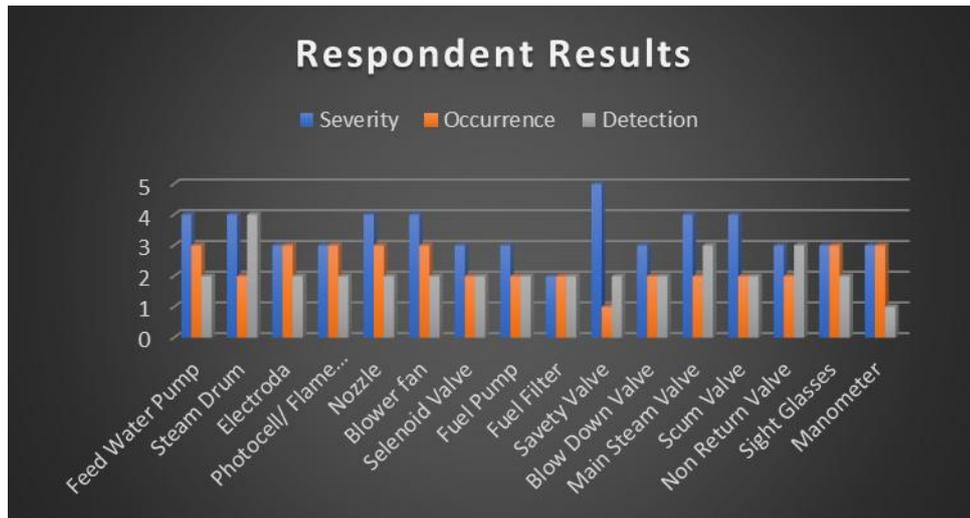*(pISSN: 2541-5972, eISSN: 2548-1479)*

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Figure. 4. Respondent Results

5. *Risk Priority Number calculation results*

The RPN value is obtained from the following formula:

$$RPN = Severity\ (S) \times Occurrence\ (O) \times Detection\ (D)$$

The results of the RPN value calculations show that 12 components are in the medium category, 1 component is in the high category, and 3 components are in the low category. The components included in the high category are located in the steam drum component with an RPN value of 32. These results indicate that the steam drum has a high risk of failure and should be a top priority for maintenance. Then, the medium category is located in 12 other components, namely the feed water pump, electrode, photocell, nozzle, blower fan, solenoid valve, fuel pump, blow down valve, main steam valve, scum valve, non-return valve, and sight glass. If a component in the medium category fails, the failure will still interfere with the boiler's performance but not as severely as components with the highest RPN value. Furthermore, components in the low category are components that have a fairly low potential for failure because they are easy to detect, including the fuel filter, safety valve, and manometer

TABLE 7.
RISK PRIORITY NUMBER CALCULATION RESULTS (SOURCE: PROCESSED DATA)

| NO.	COMPONENT	SEVERITY SCORE (S)	OCCURRENCE SCORE (O)	DETECTION SCORE (D)	RPN VALUE	CATEGORY
1.	STEAM DRUM	4	2	4	32	HIGH
2.	FEED WATER PUMP	4	3	2	24	MEDIUM
3.	NOZZLE	4	3	2	24	MEDIUM
4.	BLOWER FAN	4	3	2	24	MEDIUM
5.	NOZZLE	4	3	2	24	MEDIUM
6.	MAIN STEAM VALVE	4	2	3	24	MEDIUM
7.	ELECTRODA	3	3	2	18	MEDIUM
8.	PHOTOCELL/ FLAME EYE DETECTOR	3	3	2	18	MEDIUM
9.	NON RETURN VALVE	3	2	3	18	MEDIUM
10.	SIGHT GLASSES	3	3	2	18	MEDIUM
11.	SCUM VALVE	4	2	2	16	MEDIUM
12.	SELENOID VALVE	3	2	2	12	MEDIUM
13.	FUEL PUMP	3	2	2	12	MEDIUM
14.	SAFETY VALVE	5	1	2	10	LOW
15.	MANOMETER	3	3	1	9	LOW
16.	FUEL FILTER	2	2	2	8	LOW
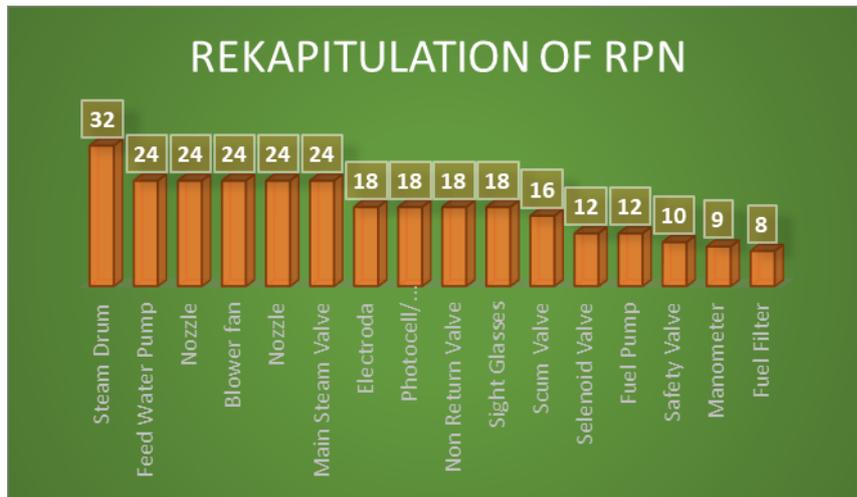
Figure. 5. Summary of Risk Priority Number Values

6. Maintenance Strategy Implications

The results of the FMEA analysis provide important insights into the effectiveness of the current boiler maintenance strategy on KM. Tilongkabila and highlight the need for maintenance prioritization based on risk levels. In an effort to improve boiler performance, several improvement recommendations are needed with the aim of reducing the risk of failure, preventing recurrence of failure, and ensuring more efficient and safer operations. Improvement recommendations have been directed according to the RPN value category for each component. The component in the high category with the highest RPN value is the steam drum. Therefore, the necessary improvement recommendations are to conduct a thorough inspection and material testing (NDT) using the ultrasonic (UT) method to detect corrosion/damage to the steam drum walls, conduct water treatment tests to test the levels (pH, alkalinity, chloride) and evaluate water treatment to prevent scale formation, and conduct pressure tests after each repair.

The recommended repairs for components in the medium category are to perform routine maintenance and operational tests, such as checking and cleaning sensors for nozzles, electrodes, photo cells, and checking seals/bearings/gaskets for gauge glasses, blower fans, solenoid valves, fuel pumps, and feed water pumps. Valve maintenance is also required, such as checking the seat, replacing the packing, and conducting manual tests. Meanwhile recommended repairs for low-category components include periodic testing and calibration, as well as replacing materials if necessary.

IV. CONCLUSION

These research aims to evaluate boiler maintenance on the KM. Tilongkabila ship. Findings show that the boiler on the ship experienced failures such as difficulty starting the engine, unstable steam pressure, scalling on several components, and incomplete combustion. This is caused by scale buildup that can inhibit heat transfer, accumulated dirt, damage or wear to bearings/rotors/seals, damaged filters resulting in incomplete combustion, seal leaks, or malfunctioning measuring devices, which can lead to thermal damage.

All failures occur due to a lack of supervision, routine maintenance schedules that are often ignored, and the engine crew's lack of knowledge in evaluating these failures. Therefore, the FMEA method is needed to evaluate boiler components in order to detect failures early.

Therefore, the researchers suggest several recommendations for improvement, whereby all engine crew must increase their supervision of all components that are at high risk of damage. The FMEA results can be used as evaluation material to ensure the effectiveness of the improvement recommendations, where the results have determined several categories for each component in the boiler and it is necessary to add a routine maintenance schedule, conduct repeated evaluations related to water treatment, and determine the appropiate improvements for each failure that occurs in the steam drum. All of this is done so that these failures do not occur again in the future. This research highlights the importance of boiler maintenance in the smooth operation of ships and provides valuable insights for engineers who want to evaluate boiler component maintenance optimally through preventive maintenance strategies.

REFERENCES

[1] BPS Indonesia, "BPS Indonesia 2023," *Statistik Indonesia*, vol. 1101001, 2023.

[2] 2023 BPS, "Impor menurut moda transportasi 2021 -2022," *Sustainability (Switzerland)*, vol. 11, no. 1, 2023.

[3] M. Retno Gunarti *et al.*, "Analisis Program Boiler Water Treatment Di Kapal," *Jurnal 7 Samudra*, vol. 6, no. 1, 2022, doi: 10.54992/7samudra.v6i1.80.

[4] A. Narto, A. Prasetiawan, and M. Syaefudin, "Analysis of the Occurrence of Combustion Failure in the Steam Boiler at KM. Nggapulu," *RSF Conference Series: Engineering and Technology*, vol. 3, no. 1, 2023, doi: 10.31098/cset.v3i1.731.

[5] A. Lestari, V. T. Situmorang, T. Tahdid, K. A. Ridwan, and A. Manggala, "Analisa Efisiensi Termal Water Tube Boiler Berdasarkan Rasio Udara Bahan Bakar LPG Untuk

International Journal of Marine Engineering Innovation and Research, Vol. 11(1), Mar. 2026. 195-203
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Memproduksi Saturated dan Superheated Steam," *Jurnal Pendidikan dan Teknologi Indonesia*, vol. 1, no. 10, 2021, doi: 10.52436/1.jpti.105.

[6] H. E. Pardosi, I. Saufi, Y. Daeli, and H. Ibrahim, "Pemanfaatan Empty Fruit Bunch Press Sebagai Bahan Bakar Pembangkit Listrik Tenaga Uap," *Sinergi PolmeD: Jurnal Ilmiah Teknik Mesin*, vol. 4, no. 1, 2023, doi: 10.51510/sinergipolmed.v4i1.997.

[7] A. Narto, M. E. Wibowo, J. Sutarto, Abdurrahman, and E. S. Budi, *Mesin Penggerak Utama Boiler (Ketel Uap): Pengantar Mahasiswa untuk Berlayar*, 1st ed. Semarang: Politeknik Ilmu Pelayaran Semarang, 2024.

[8] M. A. Rahman, P. Murti, and M. A. Ilham, "Numerical Analysis of Flow Stability in a Natural Circulation Loop," *Jurnal Inotera*, vol. 9, no. 1, 2024, doi: 10.31572/inotera.vol9.iss1.2024.id298.

[9] D. Alidina, E. Arga, K. A. Ridwan, Z. Zurohaina, and A. Syakdani, "Analisis Sistem Termal Pada Double Drum Water Tube Boiler Untuk Memproduksi Superheated Pengaruh Rasio Udara Bahan Bakar Gas," *Jurnal Pendidikan dan Teknologi Indonesia*, vol. 2, no. 1, 2022, doi: 10.52436/1.jpti.132.

[10] M. Rauch, S. Mudrinić, and A. Galović, "Entropy analysis of complete condensation of saturated steam on a vertical wall using nusselt velocity and temperature profile in a condensate layer," *Journal of Sustainable Development of Energy, Water and Environment Systems*, vol. 9, no. 1, 2021, doi: 10.13044/j.sdewes.d8.0326.

[11] S. Kim, S. Choe, J.-H. Choi, and S.-H. Choi, "Theoretical calculations for the superheated steam properties up to 8.0 MPa based on the ideal gas law with the compressibility factor Z," *Case Studies in Thermal Engineering*, vol. 72, p. 106386, Aug. 2025, doi: 10.1016/j.csite.2025.106386.

[12] kurni yusto Uswatun, hasanah ulfa Inayati, asrul osama Waiulung, and M. Ilias, "Konsep Dasar Pengukuran, Penilaian, Dan Evaluasi Hasil Belajar Pendidikan Agama Islam," *INTELEKTIVA*, vol. 6, no. 2, 2024.

[13] T. Aprianto, I. Setiawan, and H. H. Purba, "Implementasi metode Failure Mode and Effect Analysis pada Industri di Asia – Kajian Literature," *MATRIK*, vol. 21, no. 2, 2021, doi: 10.30587/matrik.v21i2.2084.

[14] Melviana, D. A. Putri, A. Qomariah, N. H. Nisa, and R. G. Nugraha, "Jurnal Kewarganegaraan," *Jurnal Kewarganegaraan*, vol. 6, no. AKTUALISASI NILAI-NILAI PANCASILA DALAM KONTEKS KEKINIAN, 2022.

[15] D. Sugiyono, "Metode penelitian kuatintatif , kualitatif dan R & D / Sugiyono," 2021.

[16] C. Starbuck, *The Fundamentals of People Analytics*. 2023. doi: 10.1007/978-3-031-28674-2.

[17] S. Kumar Akula, H. Salehfar, and S. Behzadirafi, "Comparision of Traditional and Fuzzy Failure Mode and Effects Analysis for Smart Grid Electrical Distribution Systems," in *2022 North American Power Symposium, NAPS 2022*, 2022. doi: 10.1109/NAPS56150.2022.10012165.

[18] B. R. Saputra and I. D. Widodo, "Analisis Pengendalian Risiko Keselamatan dan Kesehatan Kerja (K3) dengan Metode Failure Mode and Effect Analysis (FMEA) pada PT. ABC," *JMPM (Jurnal Material dan Proses Manufaktur)*, vol. 7, no. 2, 2023, doi: 10.18196/jmpm.v7i2.19405.

[19] B. Juanda, M. I. H. Umam, and N. Nofirza, "Analisis Resiko Kerusakan Boiler Menggunakan Metode Failure Modes Effect Analysis (FMEA) Dan Fishbone Diagram," *Matrik : Jurnal Manajemen dan Teknik Industri Produksi*, vol. 26, no. 1, pp. 25–46, Sep. 2025, doi: 10.30587/matrik.v26i1.9715.

[20] R. H. Ghifari, "Analisis Kinerja Efisiensi Mesin Boiler Type Water Tube Menggunakan Metode Input-Output Dan Failure Mode And Effect Analysis (FMEA)," Thesis, Universitas Islam Negeri Sultan Syarif Kasim Riau, Riau, 2024. Accessed: Dec. 06, 2025. [Online]. Available: http://repository.uin-suska.ac.id/id/eprint/85139

[21] A. Manggala, T. Tahdid, and Y. S. Anggriani, "ANALISIS SISTEM TERMAL PADA DOUBLE DRUM WATER TUBE BOILER UNTUK MEMPRODUKSI SATURATED STEAM PENGARUH RASIO UDARA BAHAN BAKAR," *Jurnal Pendidikan dan Teknologi Indonesia*, vol. 1, no. 12, 2021, doi: 10.52436/1.jpti.130.

[22] R. Muharni, A. A. Agasi, M. Muchlisinalahuddin, D. S. Kesuma, and A. U. Berli, "The Effect of the Gap Spark Plug Electrode to The Performance of Motorcycle GL 200 D," *METAL: Jurnal Sistem Mekanik dan Termal*, vol. 6, no. 2, 2022, doi: 10.25077/metal.6.2.84-88.2022.

[23] D. Ramadan Wahid, D. M. Kamal, and G. G. R. Gunadi, "Analisis Penyebab Kerusakan Boiler Feed Pump Turbinedengan Metode FMEA," *Prosiding Seminar Nasional Teknik Mesin*, vol. 14, no. 2, pp. 1602–1607, May 2025.

[24] I. B. Rahardja, E. Abinanda, and A. L. Siregar, "Water Tube Boiler Pabrik Kelapa Sawit Kapasitas 45 Ton/Jam," *Jurnal Citra Widya Edukasi*, vol. 14, no. 1, 2022.

[25] M. Maniruzzaman, A. K. M. S. Islam, and M. M. Alam, "Design and Development of Check Valve for Irrigation Pump," *Bangladesh Rice Journal*, vol. 25, no. 2, 2023, doi: 10.3329/brj.v25i2.62709.